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INTERPLANETARY ORIGIN OF SUPER AND SUPER GREAT GEOMAGNETIC STROMS DURING 1996-2015

A.C. PANDAY[a], SHAM SINGH[b1] AND A.P. MISHRA[c]

[a,c]Department of Physics, A.P.S.University, Rewa, M.P., India
[b]Department of Applied Sciences, Chandigarh Engineering College, Landran, Mohali, Punjab

ABSTRACT

In the present paper we studied the results on interplanetary causes of super geomagnetic storms (Dst ≤−200 nT), that occurred during solar cycle 23 and 24 (1996-2015). It was reported that the most common interplanetary structures leading to the development of intense storms were: magnetic clouds, sheath fields, sheath fields followed by a magnetic cloud and corotating interaction regions at the leading fronts of high speed streams. However, the relative importance of each of those driving structures has been shown to vary with the solar cycle phase. Super great storms (Dst ≤−300 nT) have been also studied in more detail for solar cycle 23, confirming initial studies done about their main interplanetary causes. The storms are associated with magnetic clouds and sheath fields following interplanetary shocks, although they frequently involve consecutive and complex ICME structures.

KEYWORDS : Super geomagnetic storms, Super great geomagnetic and Geomagnetic activity

The large disturbances in Earth's magnetic field are known as geomagnetic storms. They often persisting for several days are more. During geomagnetic storms, strong electric currents flowing within the Earth's magnetosphere and ionosphere perturb the magnetic field measured at the Earth's surface, the aurora brightens and extended to low magnetic latitudes, and intense fluxes of energetic charge particles are generated within the magnetosphere.

Super geomagnetic storms are those for which the storm Dst index achieves values ≤ −200 nT (Singh & Mishra 2015). Super great storms are those events for which Dst obtains values less than −300 nT (Gonzalez et al., 2002). Gonzalez and Tsurutani (1987) and Tsurutani et al., (1988) studied the interplanetary causes of super geomagnetic storms (Dst ≤−200 nT) for the peak interval of the maximum phase of solar cycle 21 and found that approximately half of the storms were associated with magnetic clouds and half with sheath field regions behind interplanetary shocks. Later, several authors have studied the geoeffectiveness of magnetic clouds for longer time intervals (Zhang et al. 1988; Gosling et al., 1991, Echer et al., 2005) and of other interplanetary structures for several levels of the intensity of magnetic storms, also involving superstorms (Gonzalez et al., 1994, Echer et al. 2006, Singh et al., 2012 Richardson et al., 2006, Gonzalez et al., 2007). Tsurutani et al., (2003) reported extreme historical storms, for which the Carrington storm of September 2, 1859 was the most large. Whereas during the space era the most super great recorded storm was that of March 13, 1989, with a peak Dst index of nearly −600 nT, the historical storms listed on Table 2 (Tsurutani et al., 2003, Singh et al., 2012) had associated peak-ring current intensity values <−600 nT.

The prevailing conditions in the solar-terrestrial environment which are a consequence of the emission of charged particles from the Sun and their interaction with the Earth's magnetic field, is called space weather. There is presently some considerable interest in forecasting space weather and data from satellites observing the Sun and the solar wind are extremely valuable.

The similarity, we have been pursuing works in part because terrestrial weather and space weather refer to phenomena manifested in fluid medium that occupy complementary volumes of space and in part because in many respects these phenomena are similar or analogous. In the troposphere these are wind, pressure, temperature, precipitation, and the state of the sky. The analogs to these for space weather are solar wind speed and ram pressure, IMF Bz, energetic particle intensity, and auroras. To the general circulation of the atmosphere there corresponds magnetospheric convection. Tropospheric storms can be extratropical, tropical, or airmass. Space storms can be CIR, CME, or background substorms. Deterministic chaos which absolutely limits the range of weather forecasts in the troposphere has its space weather analog in the sun-to-earth turbulence in the solar wind which absolutely limits deterministic forecasts of disturbance levels beyond about one hour.

Selection Criteria and Data Sources

In the present study, we have compiled a catalogue of only super geomagnetic and super great geomagnetic stroms, which are associated with Dst decrease of more than

[1]Corresponding author

-200nT to -300nT (super storm) and less than -300 nT (super- great storms) observed during the period 1996-2012 which cover the solar cycle 23 and maxima of solar cycle 24. The minimum value during a storm will be between -200nT and maximum approximately -500nT. The recovery phase is the period when Dst changes from its minimum value to its quiet time value. We have calculated geomagnetic storms when the magnitude of storms Dst value recurs for several consecutive days/hours then the last day/hour is taken as the storm day/hour. The restriction to this class of storms provided as a limited set of events suitable for a detailed study. The various geomagnetic, interplanetary and solar data measured through a number of satellites and observatories have been obtained from either on request to concerning authority or by internet. During our study period, we find that Super, Super- great geomagnetic storms and their association with CMEs or flare are falling under our section, and are listed in tables as 1, 2.

Table 1: List of Super Geomagnetic Storms

Storm No.	Date of maximum decreases in Dst value	Main Phase onset date (hrs)	Magnitude of storm ≤-200 to -300 (nT)	Initial Phase duration (hrs)	Main Phase duration (hrs)	Recovery Phase dura tion (hrs)	Longevity of storm (hrs)	Type of storm	Asso. with Flares	Asso. with CIR	Types of CMEs
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Solar Cycle 23								**1996**			
…	………	…….	………..	..Nil…	………	………	………	…			
1997											
….	………	…….	………..	..Nil…	………	………	……	**…..**			
1998											
01	May 04	05UT	-205	14	04	84	102	938	X11	----Nil--	**H**
02	Sept. 24	09UT	-207	04	07	116	127	**No CMEs**	M71	-Nil--	--Nil---
1999											
03	Oct. 22	06UT	-237	05	04	102	111	**No CMEs**	M17	-Nil--	--Nil-
2000											
04	April 06	00UT	-288	04	09	132	145	1188	M10	-Nil--	H
05	Aug. 12	09UT	-235	06	06	99	111	1071	**No Flare**	-Nil--	-Nil--
06	Sept. 18	23UT	-201	03	02	89	95	1215	M33	-Nil--	H
2001											
07	April 11	23UT	-271	06	03	92	101	2411	X23	-Nil--	H
08	Nov. 06	06UT	-292	07	07	153	167	1810	X10	-Nil-	H
09	Nov. 24	16UT	-221	05	08	137	150	1443	M12		H
2002											
….	………	…….	………..	..Nil…	………	………	……	**…..**			
2003											
….	………	…….	………..	..Nil…	………	………	……	**…..**			
2004											
….	………	…….	………..	..Nil…	………	………	……	**…..**			
2005											
10	May 15	08UT	-263	01	03	114	118	1689	M14	---Nil---	H
11	Aug. 24	11UT	-216	01	04	77	82	2378	M26	---Nil---	H
2006											
….	………	…….	………..	..Nil…	………	………	……	**…..**			
2007											
….	………	…….	………..	..Nil…	………	………	……	**…..**			
Solar Cycle 24								**2008**			
….	………	…….	………..	..Nil…	………	………	……	**…..**			
2009											
….	………	…….	………..	..Nil…	………	………	……	**…..**			
2010											
….	………	…….	………..	..Nil…	………	………	……	**…..**			
2011											
….	………	…….	………..	..Nil…	………	………	……	**…..**			
2012											

Table 2: List of Super Great Geomagnetic Storms

Storm No.	Date of maximum decreases in Dst value	Time of Event	Magnitude of storm ≤-300 (nT)	Initial Phase duration (hrs)	Main Phase duration (hrs)	Recovery Phase duration (hrs)	Longevity of storm (hrs)	**Type of storm**	**Asso. with Flares**	**Asso. with CIR**	**Types of CMEs**
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
				Solar Cycle 23				**1996**			
….	………	…….	………..	..Nil…	………	………	……	**…..**			
						1997					
….	………	…….	………..	..Nil…	………	………	……	**…..**			
						1998					
….	………	…….	………..	..Nil…	………	………	……	**…..**			
						1999					
….	………	…….	………..	..Nil…	………	………	……	**…..**			
						2000					
01	July 15	01UT	-301	05	07	73	85	1634	X19	--Nil-	H
						2001					
02	March 31	08UT	-387	03	04	94	101	1072	X17	--Nil-	--Nil-
						2002					
….	………	…….	………..	..Nil…	………	………	…….	**…..**			
						2003					
03	Oct. 10	00UT	-353	10	02	17	29	2459	**No Flare**	--Nil-	H
04	Oct. 10	22UT	-383	04	04	82	90	**No CMEs**	X17	--Nil-	--Nil-
05	Nov. 20	20UT	-422	05	05	156	166	1824	M12	--Nil-	--Nil-
						2004					
06	Nov. 08	06UT	-373	08	04	266	278	1215	X		
						2005					
….	………	…….	………..	..Nil…	…….	………	……	**…..**			
						2006					
….	………	…….	………..	..Nil…	………	………	……	**…..**			
						2007					
….	………	…….	………..	..Nil…	………	………	……	**…..**			
				Solar Cycle 24				**2008**			
….	………	…….	………..	..Nil…	………	………	……	**…..**			
						2009					
….	………	…….	………..	..Nil…	………	………	……	**…..**			
						2010					
….	………	…….	………..	..Nil…	………	………	……	**…..**			
						2011					
….	………	…….	………..	..Nil…	………	………	……	**…..**			
						2012					
….	………	…….	………..	..Nil…	………	………	…..	**…..**			

RESULTS AND DISCUSSION

The study has once again confirmed the earlier results (Gonzalez et al., 1994, Singh and Mishra 2015) that the indices which are associated with long term variation of sunspot activity sometimes show different behaviour on short term scale depending on local solar active regions and associated phenomena. Since these individual indices on a day to day basis, are affected different at different time, hence we have tried to study the major geomagnetic storms as an individual event associated with solar and interplanetary disturbances. Here we have selected only those geomagnetic storms whose Dst magnitude ≤ -100 nT, occurred during the last three decades.

Association of M and X-class flare with CMEs for super geomagnetic storms (Dst≤-200 to -300nT)

We have considered super geomagnetic storms (Dst magnitude decreases less than -200 to -300nT) during the period 1996 to 2015 which cover the solar cycle 23 and maxima of 24. The solar energetic particle (SEP) events are energetic outbursts as a result of acceleration and heating of solar plasma during solar flares and coronal mass ejections (CMEs).

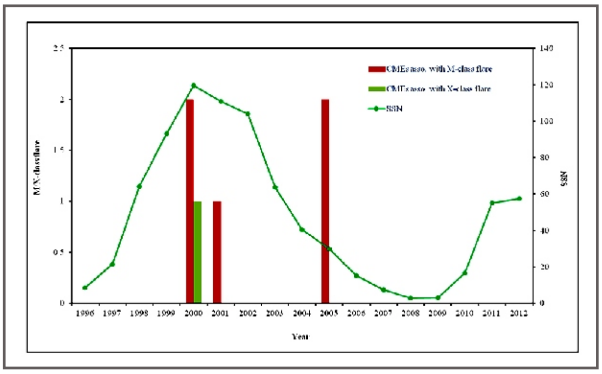

Fig. 1: Shows the occurrence of M and X-class flare associated with CMEs and SSN for super storms (Dst ≤-200 to -300 nT) during the period 1996 to 2012

Total 11 super geomagnetic storms were observed during the period 1996-2012. It is found that 72.7% (8/11) storms were associated with CMEs. Majority of these storms were associated with solar flares also. Number of storms related to M and X-class flares were 45.4% (5), and 27.2% (3) respectively, however 9% (1) storms were with CME only (without solar flares or CIR) and 18.1% (2) storms were with flares only (without association of CMEs). It shows super storms associated with CMEs are more accompanied by M-class and X-class flares, which showed in (fig 1). This figure reveals that t M-class flares has two peaks one was in solar maxima and second in declining phase of solar cycle 23. However, X-class flares follow the sunspot cycles.

Association of M and X-class flare with CMEs for super great geomagnetic storms (Dst≤-300nT)

Geomagnetic storms are intervals of time when a sufficiently intense and long-lasting interplanetary convection electric field leads, through a substantial injection of energy into the magnetosphere-ionosphere system, to an intensified ring current (Gopalswamy et al. 2004). Coronal Mass Ejections (CMEs), solar flares and the solar wind have an affect on technology and systems such as satellites, GPS and radio communications.

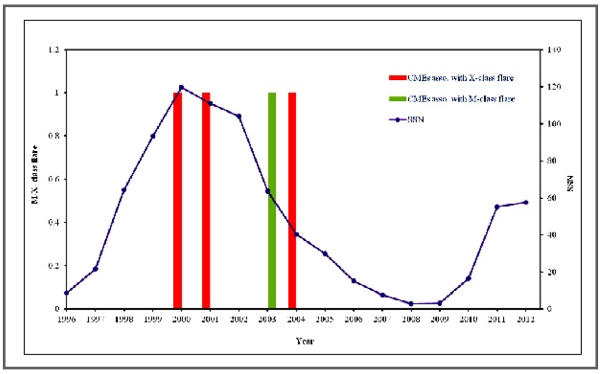

Fig. 2: Shows the occurrence of M and X-class flare associated with CMEs and SSN for super storms (Dst ≤-300 nT) during the period 1996 to 2012

In this section we have studied super great geomagnetic storms (Dst≤-300nT) and association of M, X-class flare with CMEs during the period 1996 to 2012. We have observed six super great geomagnetic storms during this period. We have identified their solar and interplanetary causes. These storms were related to CMEs observed by the Large Angle and Spectroscopic Coronagraph (LASCO). Out of six storms, 1 associated with CMEs only and 4 associated with CMEs + flare and one storm associated with flare only. We have observed only one M-class flare and the association of CMEs with M-class flare does not follow the phase of solar cycle 23 because it is maximum in year 2003, three after maxima of sunspot cycle. The association of X-class flares with CMEs maximum in year 2003 which is three after maxima of sunspot cycle (Fig. 2). We observed that 66.6% (4/6) storms were associated with CMEs. Majority of these storms were associated with solar flares also. Number of storms related to M and X-class flares were 16.6% (1) and 50% (3) respectively; however 16.6% (1) storm were associated with CME only (without solar flares or CIR) and 16% (1) storm were with flare only (without association of CMEs). It shows super great storms associated with CMEs are more accompanied by M-class and X-class flares.

CONCLUSION

The Earth's magnetosphere and upper atmosphere can be greatly perturbed by variations in the solar wind caused by disturbances on the Sun. We have observed that

72.7% (8/11) super geomagnetic storms (Dst≤-200 to -300nT) were associated with CMEs and flares. Super storms associated with CMEs are more often accompanied by M-class and X-class flares. It is observed that 66.6% (4/6) super great geomagnetic storms (Dst≤-300nT) were associated with CMEs and solar flares. Number of storms related to X-class flares or CMEs were 50% (3/6). X-class flare/CMEs are found to be responsible for super geomagnetic storms. Dst decreases with increasing magnetopause shielding currents, which is observed as a measure of magnetospheric compression produced by an increase in solar wind velocity. These quantitative relationships are invaluable for modeling studies and space weather phenomena.

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